
CHAPTER 5

**WATER
IN
SOIL**

يؤثر وجود المياه في التربة تأثيراً بالغاً على سلوكها الهندسي . ومن أهم المبادئ التي وضعها العالم الفذ ترزاكي (Terzaghi) - مؤسس علم ميكانيكا التربة - مبدأ الجهد الفعال معتبراً أن وجود المياه يؤدي إلى جهد متعادل داخل التربة وأن مقاومة وسلوك التربة الحقيقيين يجب حسابهما أخذاً في الاعتبار الجهد الفعال .

5.1 Types of water in soil

Water present in the voids of a soil mass may be broadly classified into free water and held water. The free water is free to move through a soil mass under the influence of gravity. A soil containing free water may be considered saturated under ordinary conditions. Held water is the part of water held in soil pores by some forces existing within the pores. Such water is not free to move under gravitational forces. The held water may be divided into three types, structural water, adsorbed water and capillary water.

5.1.1 Structural water المياه التركيبية

It is the water chemically combined in the crystal structure of the soil mineral and cannot be removed unless the structure is broken. Under the loadings in soil engineering, the structural water cannot be separated, and is therefore, unimportant. It cannot also be removed by oven-drying at 105-110⁰C. Therefore, the structural water is considered as part of the particle.

5.1.2 Adsorbed water المياه المندمجة

It is the part of water which the soil particles freely adsorb from atmosphere by the physical forces of attraction. Adsorbed water is held and attracted by forces within the soil by the force of adhesion which is strong enough to influence its behaviour.

It was previously explained that soil particles carry a net negative charge. Due to this charge they attract water. The attractive forces are proportional to the specific surface of the particles (specific surface is the surface area divided by volume of the particle). The attractive forces between the particles and water so adsorbed are polar bonds, and soil-water forces through the exchangeable cations. The behaviour of the adsorbed water is different from that of the pore water. The part of the adsorbed water immediately adjacent to the soil is held by forces that are so strong that water is not movable by hydrodynamic forces. Its density, freezing point, and other physical properties are different from those of ordinary liquid water. It can be considered as bound water which is a part of the effective soil particles. However, the outer portion of the adsorbed water is partially affected and can be considered as viscous water. If an oven dried soil sample is placed in moist air, the sample adsorbs moisture. Such adsorbed water varies with the temperature and the relative humidity of the air, and the characteristics of the soil particles. Coarse grained soils have relatively low adsorbed water due to their limited specific surface. The adsorbed water contents for different types of soil are as follows:

sand 1 %
silt 7 %
clay 17 %

Adsorbed water has a very definite effect on the cohesion and plasticity characteristics of fine grained soils.

5.1.3 Capillary water المياه الشعرية

It is the soil moisture located within the voids of capillary size of the soil, and held by the capillary forces. The minute pores of the soil act as capillary tubes through which the soil moisture rises above the groundwater table. The capillary forces depend upon various factors such as surface tension of water, pressure in water in relation to atmospheric pressure, and the size and configuration of soil pores.

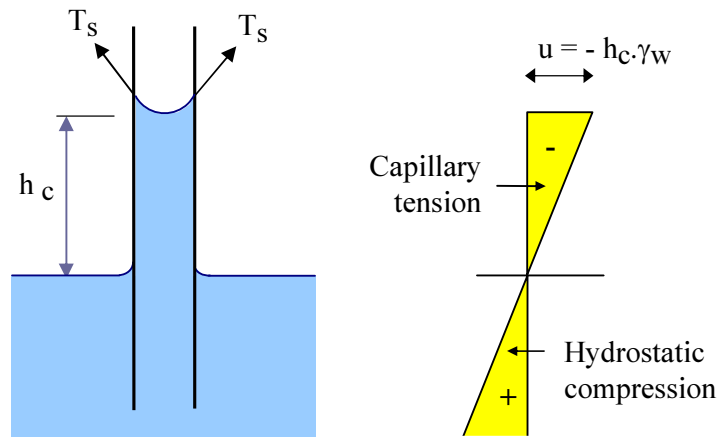


Fig 5.1 Capillary rise and corresponding pressures

The maximum height of capillary rise above groundwater surface depends upon the diameter of the capillary tube (or fineness of the pores), and the value of surface tension. Under average conditions, the maximum capillary rise is given by:

$$h_{c(\max)} = 0.304 \frac{n^3}{D_{10}} \quad \dots\dots\dots (5.1)$$

where:

$h_{c(\max)}$ = maximum capillary rise (cm)

n = porosity

D_{10} = effective diameter (cm)

The height of capillary rise in typical soil types is given in table 5.1.

Table 5.1 Average height of capillary rise

Soil type	h_c (cm)	Soil type	h_c (cm)
Fine gravel	2 - 10	Fine sand	30 - 100
Coarse sand	10 - 15	Silt	100 - 1000
Medium sand	15 - 30	Clay	1000 - 3000

5.1.4 Pore water المياه البينية

The soil contains water that is not under significant forces of attraction from the soil particles, known as pore water. Pore water follows hydrodynamic laws. Essentially all of the water in a sandy soil is pore water, less than half the water in a saturated cohesive soil may be pore or free water.

5.2 Effective and natural stresses in soil

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At any plane in a soil mass, the total stress or unit pressure (σ) is the total load per unit area. This stress may be due to:

- a) Self weight of the soil.
- b) Overburden on the soil

The total stress consists of two components:

(a) Effective stress: (inter-granular pressure σ')

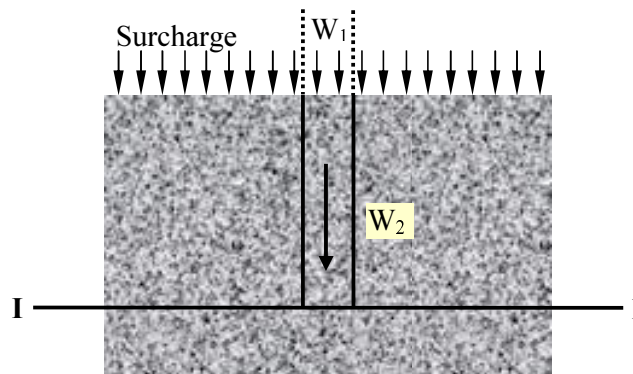


Fig 5.2 Total stress on plane I-I

It is the pressure transmitted from particle to particle through their points of contact through the soil mass above the plane. This pressure is “effective” in decreasing the void ratio of the soil mass and it also affects its shear strength.

(b) Neutral stress: (pore pressure u)

It is the pressure transmitted through the pore fluid. It has no effect on the mechanical properties of the soil. Since the total vertical pressure at any place is equal to the sum of the effective and the neutral pressures, we have:

$$\sigma = \sigma' + u \quad \text{..... (5.2)}$$

At any plane the pore pressure (u) is given by:

$$u = h_w \cdot \gamma_w \quad \text{..... (5.3)}$$

To find the value of effective stress, the following cases are considered:

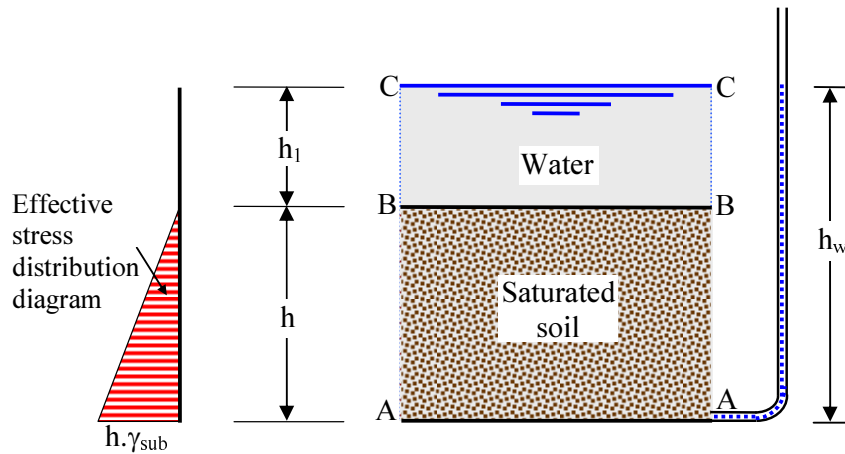
5.2.1 Submerged soil

Fig 5.3 Calculation of effective stress in submerged soil

The total, neutral and effective stresses at A-A, are given by:

$$\begin{aligned} \sigma &= h \cdot \gamma_{\text{sat}} + h_1 \cdot \gamma_w \\ u &= h_w \cdot \gamma_w \quad \sigma' = h \cdot \gamma_{\text{sub}} \end{aligned}$$

Hence, the effective pressure does not depend upon the height (h_1) of the water column. Even if h_1 reduces to zero, σ' will not change as long soil mass above the plane A-A remains saturated. At B-B the effective

pressure is zero. Thus, the effective pressure varies linearly with depth as shown in Fig. 5.3.

5.2.2 Soil with surcharge

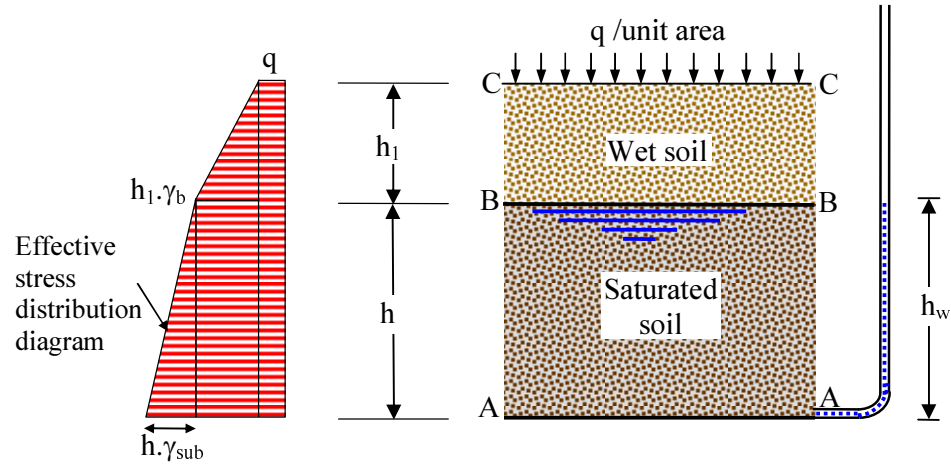


Fig 5.4 Calculation of effective stress in loaded soil

Consider a wet soil mass of height h_1 above a saturated soil mass of height h . Soil carries a surcharge load of intensity q per unit area, Fig. 5.4. The total, neutral and effective stresses at A-A are given by:

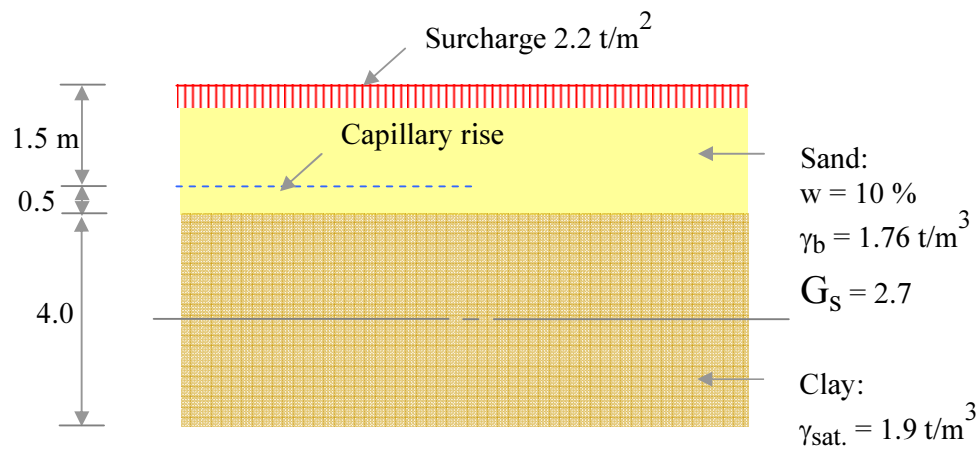
$$\sigma = q + h_1 \cdot \gamma_b + h \cdot \gamma_{\text{sat}}$$

$$u = h_w \cdot \gamma_w$$

$$\sigma' = q + h_1 \cdot \gamma_b + h \cdot \gamma_{\text{sub}}$$

5.3 Examples

(1) Calculate the total, neutral and effective stresses at the center line of the shown clay layer. Calculate the effective stress after application of a surcharge of 2.2 t/m^2 .



Solution:

$$\gamma_b = \frac{G_s + e \cdot S}{1 + e} \gamma_w$$

$$\& e \cdot S = G_s \cdot w$$

$$1.76 = \frac{2.66 + 2.66(0.1)}{1 + e}$$

$$\therefore e = 0.663$$

$$\gamma_{\text{sat.}} = \frac{G_s + e}{1 + e} \gamma_w$$

$$= \frac{2.66 + 0.663}{0.663} = 2.0 \text{ t/m}^3$$

At C.L. of the clay layer :

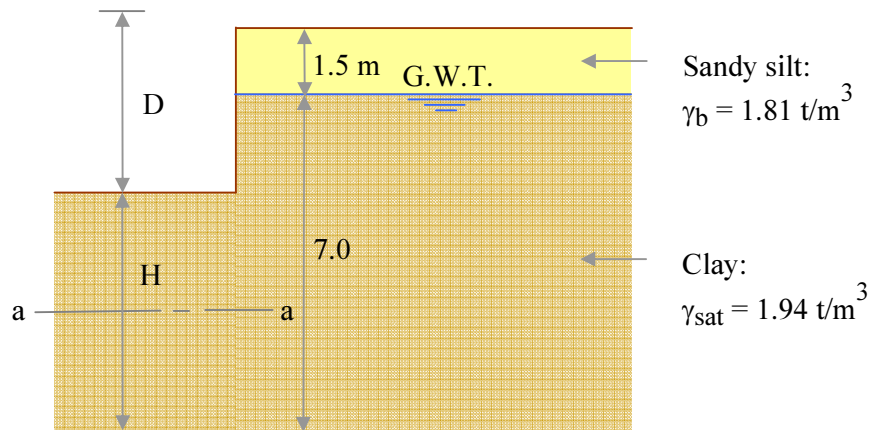
$$\sigma = 1.76 \times 1.5 + 2 \times 0.5 + 1.9 \times 2 = 7.44 \text{ t/m}^2$$

$$u = 2 \text{ t/m}^2$$

After application of surcharge :

$$\sigma' = 5.44 + 2.2 = 7.64 \text{ t/m}^2$$

(2) For the shown soil formation, calculate (D) such that the effective stress at the center line of the remaining part of the clay layer after excavation is 25 % of that before excavation.



Solution:

Before excavation :

$$\begin{aligned}\sigma'(a-a) &= 1.81 \times 1.5 + 0.94 \times \left(7 - \frac{H}{2}\right) \\ &= 9.295 - 0.47 H\end{aligned}$$

After excavation :

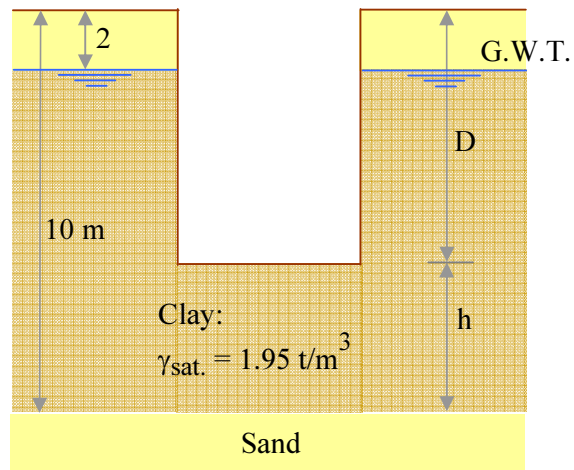
$$\sigma'(a-a) = 0.94 \times \frac{H}{2} = 0.47 H$$

$$\therefore 0.47 H = \frac{1}{4}(9.295 - 0.47 H)$$

$$\therefore H = 3.96 \text{ m}$$

$$\& D = 4.54 \text{ m}$$

(3) It is required to excavate a trench in the shown soil formation. Find the depth to which the excavation can be safely carried out without causing instability due to the uplift of the groundwater. Find the lowered groundwater depth, if the excavation is to be extended to 7 m.



Solution:

For stability :

$$1.95 \times h = 8$$

$$\therefore h = 4.12 \text{ m}$$

$$\& D = 5.88 \text{ m}$$

In case excavation is extended to 7 m depth :

$$1.95 \times 3 = h_1$$

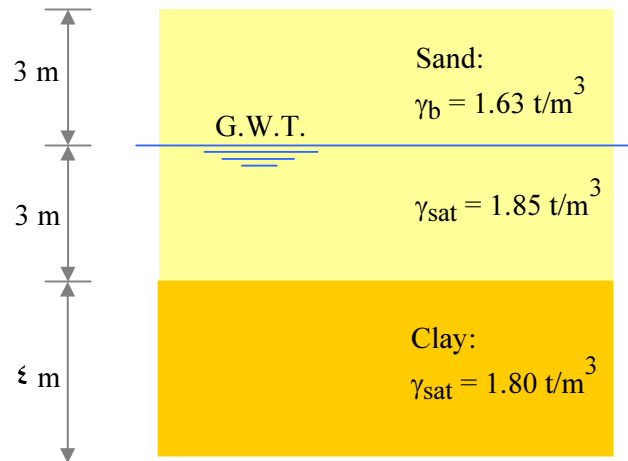
$$\therefore h_1 = 5.84 \text{ m}$$

$$\therefore \text{G.W.T. is to be lowered a distance} = 8 - 5.84 = 2.16 \text{ m}$$

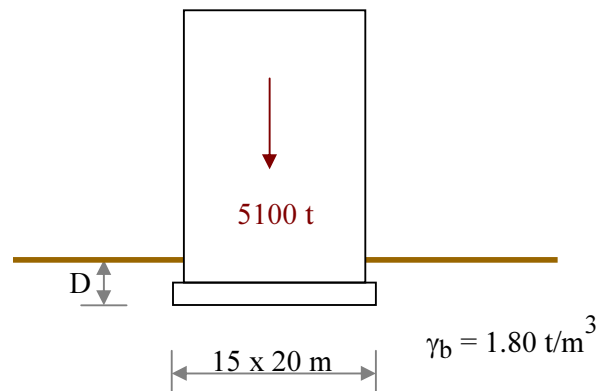
$$\text{Lowered depth of G.W.T.} = 2 + 2.16 = 4.16 \text{ m}$$

5.4 Problems

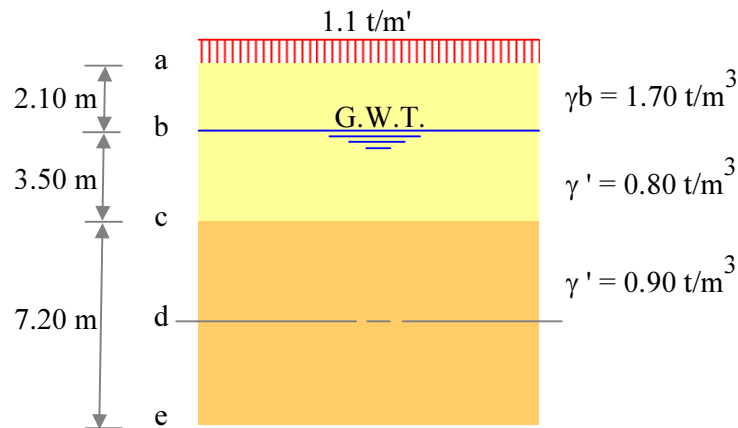
(1) Find the overburden effective stress at the center line of the shown clay layer. Find the change of this stress due to lowering of the G.W.T. from the shown position to the top of the clay layer. No allowance for capillary rise is required.



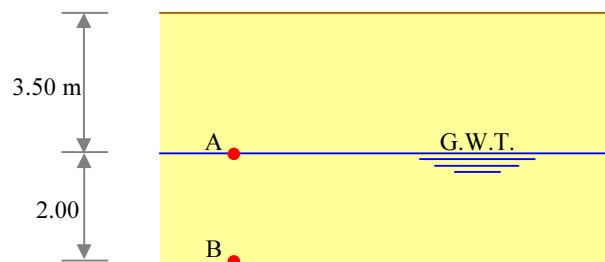
(2) For the shown building, find the depth (D) so that the increase of effective stress on soil at foundation level does not exceed 0.8 kg/cm^2 .



(3) For the shown soil formation, calculate the effective stress at points a, b, c, d and e. Draw the effective stress distribution on the line a-e.



(4) For the shown soil formation, find the effective stresses at points A and B. The dry density of sand is 1.5 t/m^3 and its specific gravity is 2.65. Take capillary rise = 0.5 m . Assume constant void ratio.



(5) The soil at a site consists of saturated silt whose water content is 42.6 % and specific gravity 2.68. The groundwater depth is 2.5 m. Find the depth of foundation (D) for a building weighing 8050 t, so that the net increase of effective stress on the soil at foundation level does not exceed 1.0 kg/cm^2 . The foundation is a raft 28 m long and 19 m wide.

(6) The bed of a lake consists of clay whose water content is 48% and specific gravity 2.71. The water depth in the lake is 5 m. Calculate the effective stress at a point 5 m below the level of the lake bed.

